

ELECTRONIC FUNDAMENTALS

EXPERIMENT LESSON 16

RESONANCE EXPERIMENTS



RCA INSTITUTES, INC.

**A SERVICE OF RADIO CORPORATION OF AMERICA
HOME STUDY SCHOOL**

350 West 4th Street, New York 14, N. Y.

Experiment Lesson 16

OBJECT

To study the behavior of alternating-current circuits containing resistance, inductance, and capacitance connected in series and in parallel.

PREPARATION

In order to get the most out of these experiments, read Theory Lesson 16 on alternating current circuits thoroughly. Be sure that you understand all the material in that lesson before you do these important experiments.

EQUIPMENT NEEDED

Capacitor board prepared in Lesson 15

Receiver chassis

Multimeter

A-C line cord and plug

One 1,000-ohm 5-watt resistor

One 1,000-ohm 2-watt resistor

One 100-ohm 1/2-watt resistor

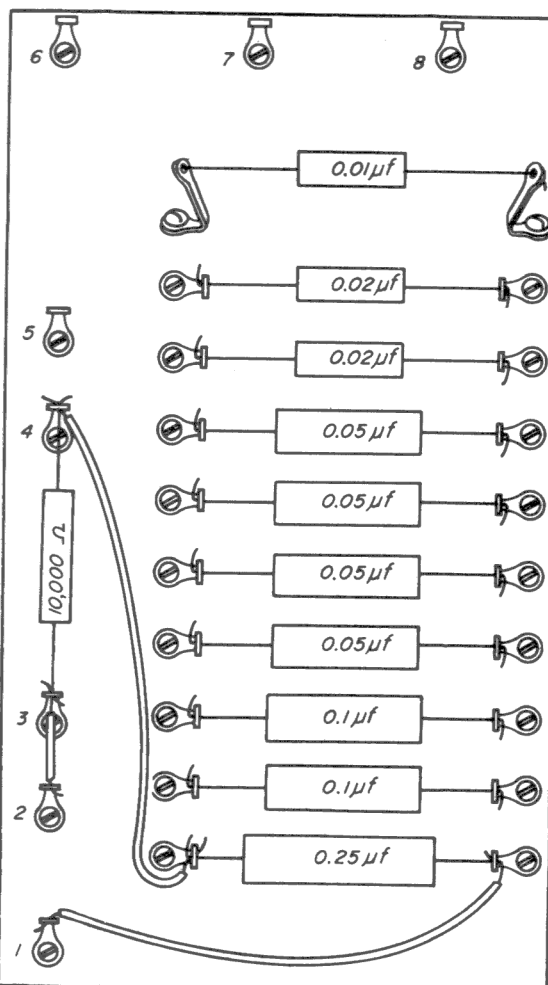
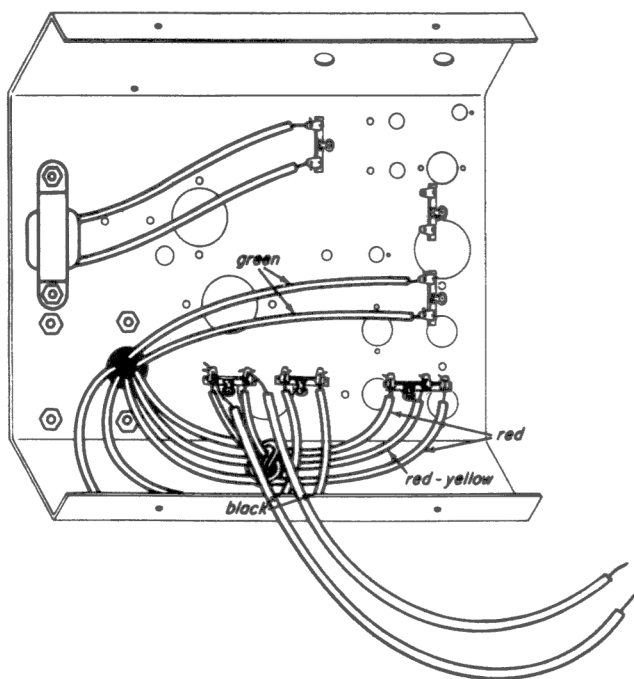


Fig. 16-1

Caution: In these experiments, the voltage across the inductor or the voltage across the capacitors may rise to several times the line voltage. The capacitors may become highly charged. After performing each step of the experiment, always disconnect the a-c line and discharge the capacitors before making any changes in the circuit.

Also, to protect your meter, get into the habit of always returning the RANGE switch on the meter to the highest scale after each measurement. Then turn the RANGE switch to a lower range, if necessary, for the next measurement. It may take a little longer, but it's better than burning out your meter. Your meter is one of the most valuable pieces of test equipment that you have. Learn to protect it.

EXPERIMENT 16-1

To obtain the resonance curve of a series a-c circuit containing resistance, inductance, and capacitance.

Procedure

Step 1. Place the receiver chassis upside

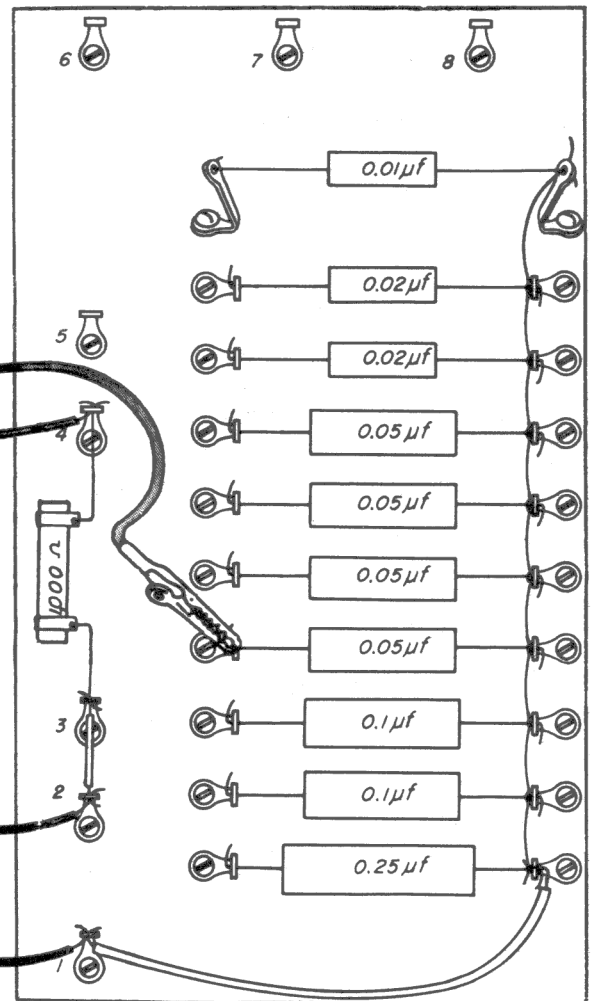
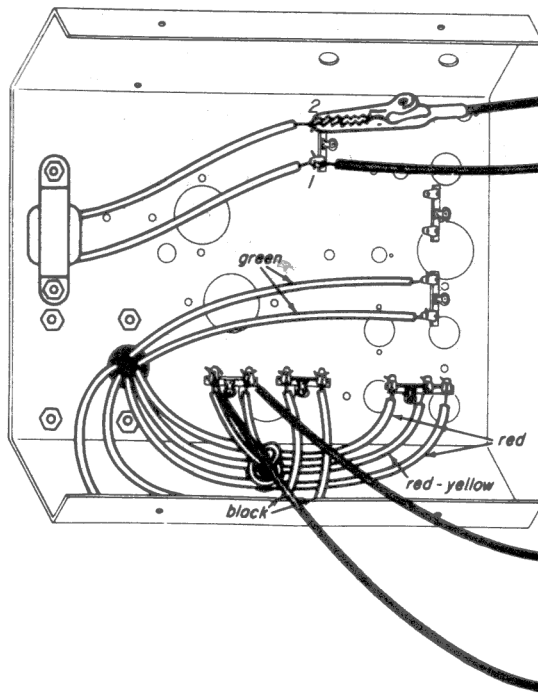


Fig. 16-2

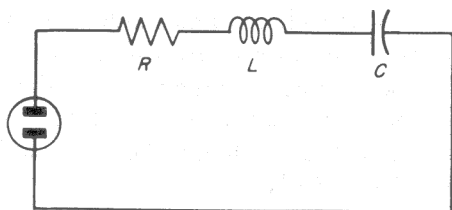


Fig. 16-3

Step 5. With your clip lead, connect lug 2 of the choke terminal strip and the free end of a $0.05\text{-}\mu\text{f}$ capacitor, as shown in the figure.

Step 6. Solder the leads from the lugs of the line-cord terminal strip on the receiver chassis (shown hanging free in Fig. 16-1) to lugs 1 and 2 on the capacitor board. You now have a circuit with resistance, inductance, and capacitance in series as shown in Fig. 16-3.

Step 7. Check your wiring with Fig. 16-2; then plug the line cord into an a-c outlet.

Step 8. Using the a-c ranges of your multimeter, measure the voltage across the line (at the line-cord terminal strip), the voltage across the resistor, the voltage across the inductor (at the choke terminal strip), the voltage across the $0.05\text{-}\mu\text{f}$ capacitor, and the voltage across both the inductor and capacitor. Record these voltages on line 1 of Table A. The current reading called for in the last column of Table A may be found by taking the voltage across the resistor and dividing it by the value of resistance. Since the resistance equals 1,000 ohms, the current in milliamperes has the same numerical value as the voltage across the resistor. So just copy this value for I_{LINE} .

Step 9. Remove the line cord from the outlet. Discharge the capacitor.

Step 10. Remove the alligator clip from the $0.05\text{-}\mu\text{f}$ capacitor and connect it to one of the $0.1\text{-}\mu\text{f}$ capacitors.

Step 11. Plug the line cord into the a-c outlet and measure and record E_R , E_L , E_C , and E_{LC} on line 2 of Table A. Be sure to fill in the I_{LINE} column.

Step 12. Remove the line cord from the outlet and discharge the capacitor.

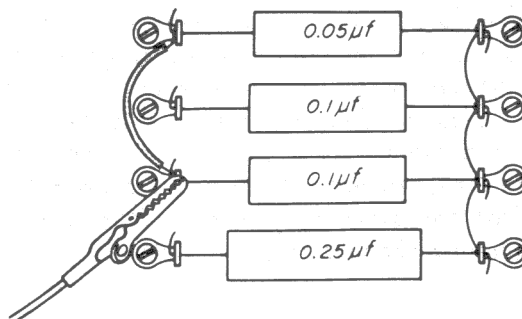


Fig. 16-4

Step 13. Connect a short insulated jumper from the $0.1\text{-}\mu\text{f}$ capacitor to the $0.05\text{-}\mu\text{f}$ capacitor to obtain a total capacity of $0.15\text{-}\mu\text{f}$, as shown in Fig. 16-4. Repeat Step 11, entering your readings on line 3 of Table A.

Step 14. Repeat Step 12.

Step 15. Follow the instructions in the first column of Table A, moving the alligator clip and adding capacity in parallel with short jumpers to get the total capacity called for in each line of the table, starting with line 4. After obtaining each total capacity value called for in the table, measure and record the voltages and current in the table, as before, up to line 13.

Caution: Be sure that all circuit changes are made with the line cord disconnected from the a-c outlet and with the capacitors discharged. When the combination of inductor and capacitor nears the 60-cycle resonance point, the reactive voltages may become so large that you must change the multimeter to the 1500 VAC range. When you have completed this series of steps, remove the line cord from the a-c outlet and discharge the capacitors.

Step 16. Locate the resonance point by examining the reactive-voltage and line-current readings recorded in Table A.

Information. At resonance, the line current and the resistor voltage are maximum, while the voltage across the combination of capacitor and inductor is minimum. A typical set of readings near resonance is shown in Table B. Your readings may not necessarily be close to those shown in Table B or to the complete set shown in Table D. Because of the large variations in iron-cored

TABLE A

	Parallel Capacitors	Total Capacity	E_R	E_L	E_C	E_{LC}	I_{LINE} (calculated in ma)
1.	Start with 0.05 μf	0.05 μf	2.2	16.2	145	122	2.2
2.	Remove 0.05 μf , use 0.1 μf	0.1 μf	5.9	53	173	122	5.9
3.	Use 0.1 μf in parallel with 0.05 μf	0.15 μf	11.4	95	216	120	11.4
4.	Use two 0.1 μf capacitors in parallel	0.20 μf	18	148	264	116	18
5.	Remove all capacitors, use 0.25 μf	0.25 μf	27	202	300	111	27
6.	Add 0.05 μf in parallel	0.30 μf	39	276	360	103	39
7.	Remove 0.05 μf , add 0.1 μf to 0.25 μf	0.35 μf	52	340	420	86	52
8.	Add 0.05 μf	0.40 μf	60	380	430	66	60
9.	Remove 0.05 μf , add 0.1 μf	0.45 μf	66	400	420	55	66
10.	Add 0.05 μf	0.50 μf	66	400	380	56	66
11.	Add 0.05 μf	0.55 μf	56	340	280	80	56
12.	Add 0.05 μf	0.60 μf	44	300	204	98	44
13.	Add 0.05 μf	0.65 μf	38	265	160	104	38
14.	Add 0.01 μf	0.66 μf	66	398	400	53	66
15.	Remove 0.01 μf , use 0.02 μf instead	0.47 μf	67	400	398	52	67
16.	Add 0.01 μf	0.48 μf	69	400	398	52	69
17.	Remove 0.01 μf , use 0.02 μf instead	0.47 μf	69	390	375	53	69
18.	Add 0.01 μf						

$$E_{LINE} = \frac{122}{\text{volts}}$$

our more steps (7 steps also) for the first of these new readings of Table A and record the others

TABLE B

Capacity	E_R	E_L	E_C	E_{LC}	I_{Line}
0.40 μf	50 v	290 v	325 v	60 v	50 ma
0.45 μf	55 v	300 v	315 v	50 v	55 ma
0.50 μf	55 v	305 v	285 v	50 v	55 ma
0.55 μf	50 v	280 v	250 v	60 v	50 ma

components, differences in readings of much more than $\pm 20\%$ may be expected. As long as the principle of resonance is demonstrated, you may consider your experiment successful.

Note that the line current and the voltages across the resistor and across the LC combination show no change at either the 0.45- μf or 0.50- μf steps. This shows that resonance has been passed through, and that the resonant point is somewhere between 0.45 μf and 0.50 μf . Using the figures obtained from your measurements, you can determine between what two 0.05- μf steps resonance occurs. Then you can find out exactly where resonance does occur. You can do this by starting at the lower of the two 0.05- μf steps and add only 0.01 μf for each step until you pass through resonance again. When this experiment was performed in our lab, resonance was passed between the 0.45- and 0.50- μf steps (as you saw in Table B). The lower of the two steps was 0.45 μf ; and it was from this point that we added 0.01 μf in Step 15.

Step 17. When you have found between what two 0.05- μf steps resonance was passed in your experiment, note how much capacity was in the circuit at the lower 0.05- μf step. Start by adding 0.01 μf to this capacity and measure and record the voltages and current as before. Continue adding 0.01- μf capacity and recording measurements for four more steps (5 steps altogether). Enter the first of these new readings on line 14 of Table A and record the others

below it. In each 0.01- μf step, record the amount of total capacity in the circuit in the Total Capacity column in the same table.

Step 18. Plot the values of line current (I_{LINE}) against capacity on the graph paper provided in Fig. 16-5. Instructions for plotting graphs from a table of data (facts or figures) are given at the end of this lesson. Refer to these instructions if you do not know how to plot your graph.

Step 19. Calculate the impedance of the inductance at resonance:

$$Z_L = \frac{\text{Voltage across inductor}}{\text{Line Current}} = \frac{E_L}{I} = \frac{400}{.069} = 5800 \Omega$$

Step 20. Calculate the impedance of the capacitor at resonance:

$$Z_C = \frac{\text{Voltage across the capacitor}}{\text{Line current}} = \frac{E_C}{I} = \frac{398}{.069} = 5800 \Omega$$

Step 21. Calculate the impedance of the inductance and capacitance in series at resonance:

$$Z_{LC} = \frac{\text{Voltage across LC combination}}{\text{Line Current}} = \frac{E_{LC}}{I} = \frac{52}{.069} = 750 \Omega$$

EXPERIMENT 16-2.

To study the effect that resistance has on the sharpness of the resonance curve of a series-tuned circuit.

Procedure

Step 1. Make sure that the line cord is disconnected from the a-c outlet and that the capacitors are discharged.

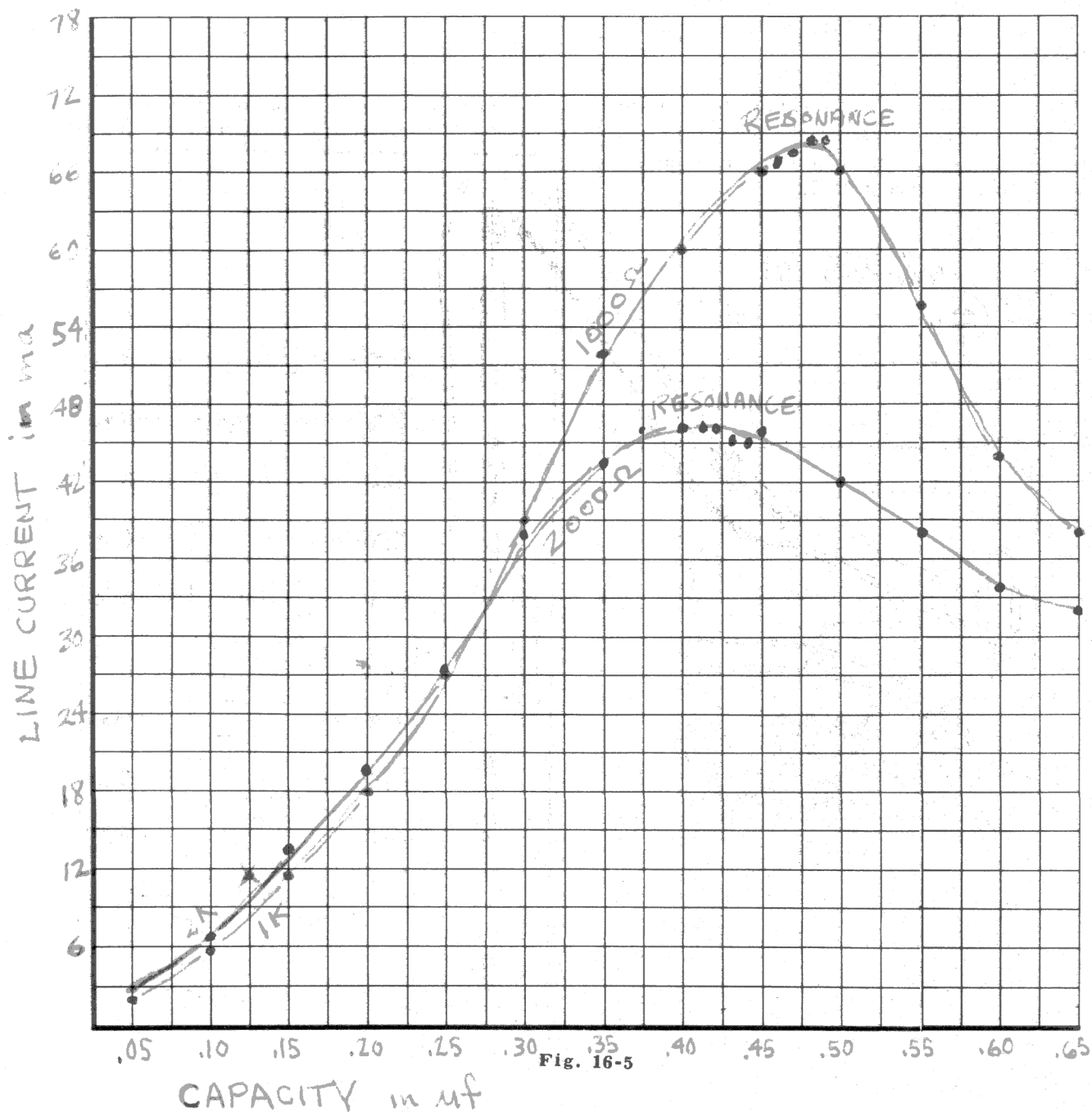
Step 2. Remove all jumper leads that connect the capacitors in parallel. Do not dis-

connect the bare wire connecting all the capacitors together on one side.

Step 3. Reconnect the clip lead to a $0.05\text{-}\mu\text{f}$ capacitor.

Step 4. Disconnect the lead at lug 4 on the capacitor board and connect it to lug 6 on the board.

Step 5. Solder the $1,000\text{-ohm}$ 2-watt resistor to lugs 5 and 6 on the capacitor board.



Step 6. Solder a short lead to lugs 4 and 5 on the capacitor board.

Step 7: Check your wiring with Fig. 16-6 and then plug the line cord into the a-c outlet.

Step 8. Measure the voltage across *one* of the 1,000-ohm resistors, across the capacitor, across the inductor, and across the capacitor and inductor in series. Record the measurements in Table C. Record I_{LINE} .

Step 9. Repeat Step 8 for all the capacity values called for in the second column of Table C. Follow the instructions in the first column of the table to obtain these capacity values.

Step 10. After locating the approximate resonant point, go through the resonant point in $0.01 \mu f$ steps as described in Steps 16 and 17 of Experiment 16-1.

Note: The resonant point will be slightly different from that found in Experiment 16-1. This is because the additional 1,000 ohms of resistance has reduced the current in the circuit, and the inductance of the iron-core choke becomes higher. So, resonance will probably occur at a lower value of capacity.

Step 11. Plot the graph of line current against capacity for this experiment, using the same sheet of paper on which the curve for Experiment 16-1 was plotted. Label each curve with the value of the series resistance with which it is related.

DISCUSSION

These first two experiments illustrate the effects of resonance in a-c series tuned cir-

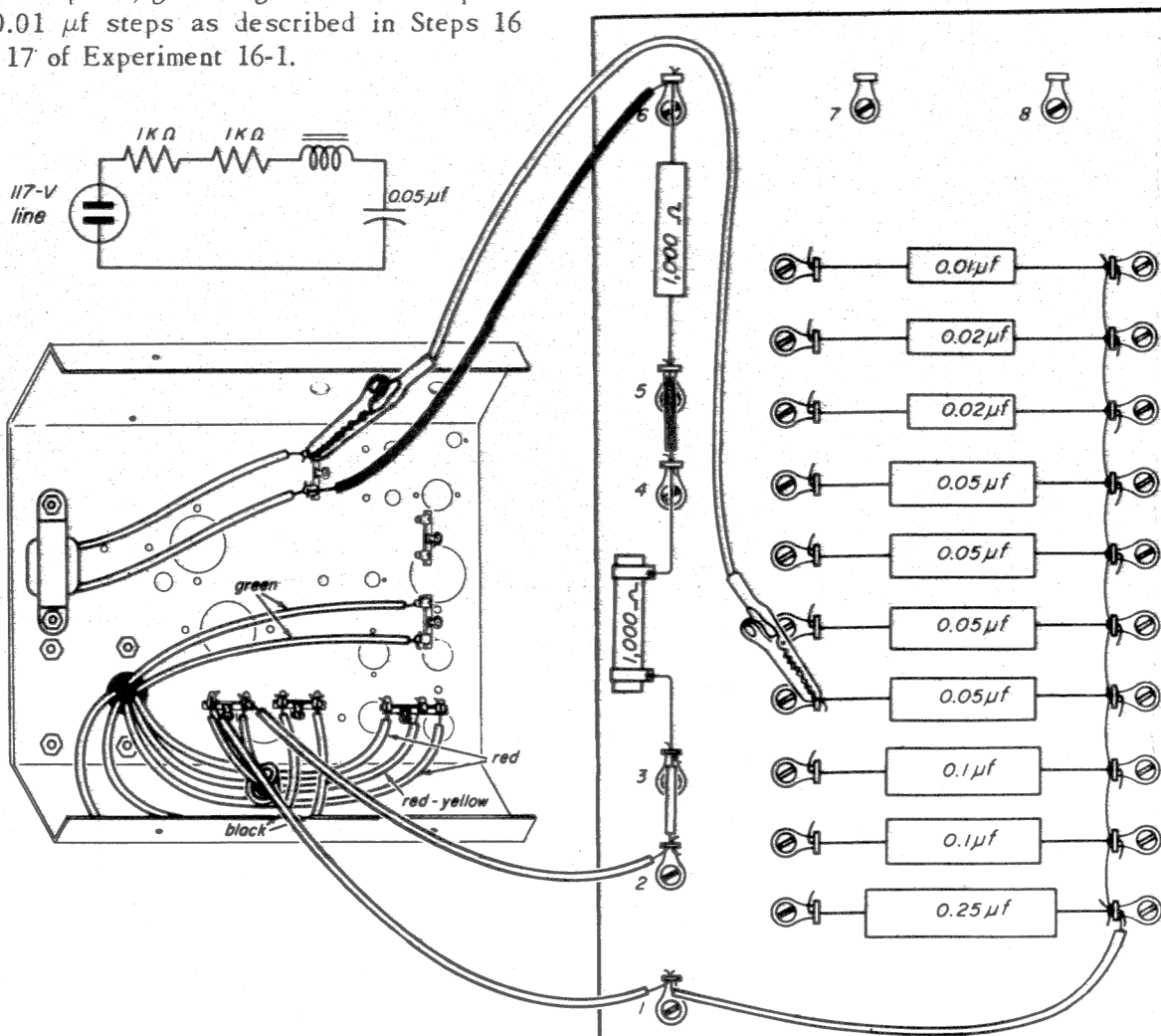


Fig. 16-6

TABLE C

	Parallel Capacitors	Total Capacity	E_R	E_L	E_C	E_{LC}	I_{LINE} (calculated in ma)
1.	Start with 0.05 μf	0.05 μf	2.6	21	144	122	2.6
2.	Remove 0.05 μf , use 0.1 μf	0.1 μf	6.5	52	174	118	6.5
3.	Use 0.1 μf in parallel with 0.05 μf	0.15 μf	13.4	90	210	115	13.4
4.	Use two 0.1 μf capacitors in parallel	0.20 μf	19	140	248	108	19
5.	Remove all capacitors, use 0.25 μf	0.25 μf	27	184	278	96	27
6.	Add 0.05 μf in parallel	0.30 μf	35	232	290	72	35
7.	Remove 0.05 μf , add 0.1 μf to 0.25 μf	0.35 μf	43	265	300	51	43
8.	Add 0.05 μf	0.40 μf	46	275	278	34	46
9.	Remove 0.05 μf , add 0.1 μf	0.45 μf	46	272	245	41	46
10.	Add 0.05 μf	0.50 μf	42	256	204	53	42
11.	Add 0.05 μf	0.55 μf	38	238	170	72	38
12.	Add 0.05 μf	0.60 μf	34	222	140	80	34
13.	Add 0.05 μf	0.65 μf	32	208	116	88	32
14.	Add 0.01 μf	.41	46	278	264	35	46
15.	Remove 0.01 μf , use 0.02 μf instead	.42	46	276	256	38	46
16.	Add 0.01 μf	.43	45	272	248	40	45
17.	Remove 0.01 μf , use 0.02 instead	.44	45	270	240	44	45
18.	Add 0.01 μf						

Resonance $\rightarrow$

E_{LINE} 122 volts

cuits. The measurements that were recorded for these experiments when they were performed in our lab are shown in Tables D and E. Table D shows the data taken with 1,000 ohms of series resistance, and Table E shows the data taken with 2,000 ohms of series resistance. Your figures may not be exactly like those shown in the tables; they are given only so that you may know what to expect in the way of readings so you can tell whether or not you are on the right track.

Your experimental results should show these important points about a series-tuned circuit at resonance:

1. The line current is at its maximum value.
2. The circuit impedance is at its minimum value.
3. The voltage across the inductor and capacitor combined is at its minimum value.
4. The sharpness of the series-resonance curve depends upon the resistance in the circuit: the lower the series resistance, the sharper is the resonance curve.

Resonance occurs in a series circuit because the voltage across the capacitor and the voltage across the inductor are almost 180 degrees out of phase. (They are never exactly 180 degrees out of phase due to the resistance contained within the inductor.) Being almost exactly opposite, the voltages across the inductor and capacitor cancel each other, as shown by the fact that the voltage readings across the capacitor and inductor combined (E_{LC}) are minimum at resonance. This voltage is actually the vector sum of the inductive voltage and the capacitive voltage. Because there is always some voltage drop due to the resistance of the inductor, the vector sum of the reactive voltages cannot ever be zero. However, it becomes minimum at resonance. As a result, the impedance of the circuit is minimum and the current in the circuit is maximum. Also, because the current is high, the voltage drop across the inductor and across the capacitor is very high, and is equal to the current times

the reactance; or, Q times the line voltage. At resonance, the voltage across the inductor almost equals the voltage across the capacitor. However, the voltage across the capacitor is at its highest value when the circuit is slightly off resonance, when the capacity is slightly smaller than the value required for resonance.

As your curves should show, the sharpness of resonance depends upon the amount of resistance in the circuit. Putting additional resistance in series with the circuit reduces the maximum current that flows, and reduces the sharpness of resonance. Typical curves for this experiment are given in Fig. 16-7. When comparing the sharpness of resonance of the two curves, disregard the fact that the resonant point has also shifted (due to the lower current in the iron core inductor, the inductance increased and resonance was obtained with less capacitance).

EXPERIMENT 16-3

To study the action of inductance and capacitance in producing resonance in a parallel tuned a-c circuit.

Procedure.

Step 1. Remove all jumper leads that connect the capacitors in parallel. Do not remove the bare wire connecting all the capacitors together on one side.

Step 2. Unsolder the 1,000-ohm resistor from lugs 5 and 6 on the capacitor board.

Step 3. Remove the lead between lugs 4 and 5.

Step 4. Unsolder the choke lead from lug 6 on the capacitor board and solder it, instead, to lug 1.

Step 5. Remove the alligator clip from choke terminal lug 2 and connect it to lug 4 on the capacitor board. Connect the other alligator clip to one of the 0.05- μ f capacitors.

Step 6. Solder a lead from lug 4 on the

TABLE D
SERIES CIRCUIT WITH 1,000 OHMS RESISTANCE

	Parallel Capacitors	Total Capacity	E_R	E_L	E_C	E_{LC}	I_{LINE} (calculated in ma)
1.	Start with 0.05 μf	0.05 μf	2.5	20	130	110	2.5
2.	Remove 0.05 μf , use 0.1 μf	0.1 μf	5.4	42	150	109	5.4
3.	Use 0.1 μf in parallel with 0.05 μf	0.15 μf	10.6	85	190	106	10.6
4.	Use two 0.1 μf capacitors in parallel	0.20 μf	16	125	225	105	16
5.	Remove all capacitors, use 0.25 μf	0.25 μf	30	200	295	95	30
6.	Add 0.05 μf in parallel	0.30 μf	37.5	250	310	80	37.5
7.	Remove 0.05 μf , add 0.1 μf to 0.25 μf	0.35 μf	45	280	335	70	45
8.	Add 0.05 μf	0.40 μf	50	290	325	60	50
9.	Remove 0.05 μf , add 0.1 μf	0.45 μf	55	300	315	50	55
10.	Add 0.05 μf	0.50 μf	55	305	285	50	55
11.	Add 0.05 μf	0.55 μf	50	280	250	60	50
12.	Add 0.05 μf	0.60 μf	40	255	175	80	40
13.	Add 0.05 μf	0.65 μf	33	205	135	90	33

APPROACHING RESONANCE

14.	Add 0.01 μf	0.464f	55	300	310	49	55
15.	Remove 0.01 μf , use 0.02 μf instead	0.474f	56	300	305	47	56
16.	Add 0.01 μf	0.484f	57	300	300	45	57
17.	Remove 0.01 μf , use 0.02 instead	0.494f	56	305	295	47	56
18.	Add 0.01 μf	0.504f	55	305	285	50	55

E_{LINE} 110 volts

TABLE E
SERIES CIRCUIT WITH 2,000 OHMS RESISTANCE

	Parallel Capacitors	Total Capacity	E_R	E_L	E_C	E_{LC}	I_{LINE} (calculated in ma)
1.	Start with 0.05 μf	0.05 μf	2.5	19	104	110	2.5
2.	Remove 0.05 μf , use 0.1 μf	0.1 μf	5.2	41	150	107	5.2
3.	Use 0.1 μf in parallel with 0.05 μf	0.15 μf	10.2	80	180	102	10.2
4.	Use two 0.1 μf capacitors in parallel	0.20 μf	15	120	210	97	15
5.	Remove all capacitors, use 0.25 μf	0.25 μf	25	175	250	75	25
6.	Add 0.05 μf in parallel	0.30 μf	31	210	253	55	31
7.	Remove 0.05 μf , add 0.1 μf to 0.25 μf	0.35 μf	35	230	255	45	35
8.	Add 0.05 μf	0.40 μf	36	235	230	38	36
9.	Remove 0.05 μf , add 0.1 μf	0.45 μf	34	230	195	45	34
10.	Add 0.05 μf	0.50 μf	30	220	170	55	30
11.	Add 0.05 μf	0.55 μf	27	205	140	65	27
12.	Add 0.05 μf	0.60 μf	25	180	115	75	25
13.	Add 0.05 μf	0.65 μf	24	170	110	80	24

APPROACHING RESONANCE

14.	Add 0.01 μf	0.364f	35.5	233	250	43	35.5
15.	Remove 0.01 μf , use 0.02 μf instead	0.374f	36	235	245	40	36
16.	Add 0.01 μf	0.384f	36.5	235	240	38	36.5
17.	Remove 0.01 μf , use 0.02 instead	0.394f	37	235	235	37	37
18.	Add 0.01 μf	0.404f	36	235	230	38	36

E_{LINE} 110 volts

capacitor board to lug 2 on the choke terminal strip.

Step 7. Check your wiring against Fig. 16-8. If it is correct, connect the line cord to the a-c outlet.

Step 8. Measure the line voltage, the voltage across the 1,000-ohm resistor, and the

voltage across the parallel circuit (E_{tank} , measured across L or C). Record your measurements in Table F.

Step 9. Repeat Step 8 for every capacity value listed in the second column of the table. The first column of the table gives directions for obtaining each of the capacity values called for in the first column.

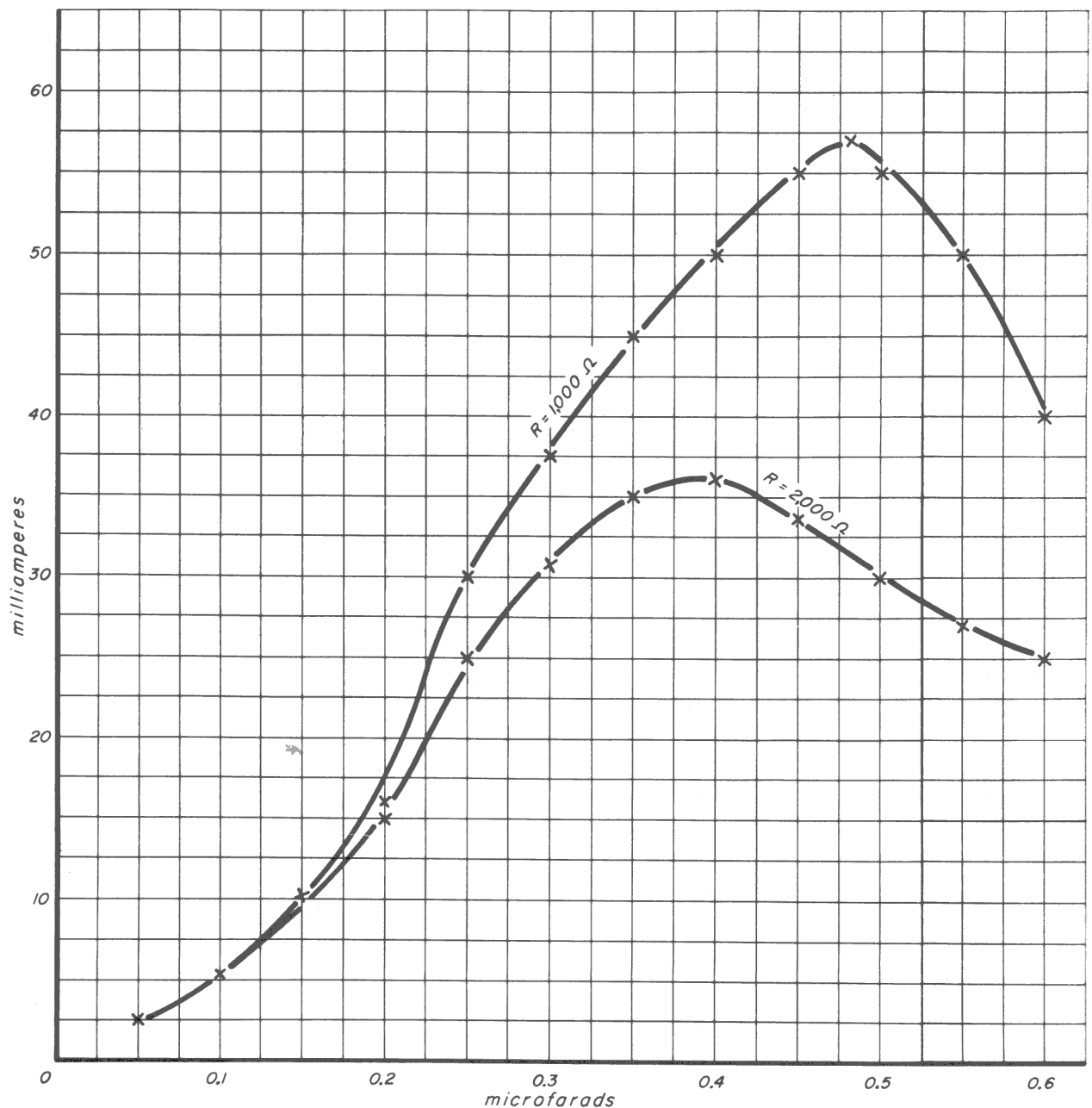


Fig. 16-7

Step 10. Locate the resonance point by examining the readings that you have recorded in this experiment.

Information. To locate the resonant point in a parallel-tuned circuit, you have only the current to guide you. Let us examine a typical set of readings recorded in our lab (Table G). Only the current readings taken near resonance are shown in the table.

Note that as capacity is added, the current

first decreases and then increases. We know that in a parallel tuned circuit, the current is minimum at resonance. Looking at the figures in Table G, we can see that the circuit has passed through resonance.

But just exactly where is the resonant point? Is it between the $0.30\text{-}\mu\text{f}$ and $0.35\text{-}\mu\text{f}$ steps, as shown in Fig. 16-9a? Is it between the $0.35\text{-}\mu\text{f}$ and $0.40\text{-}\mu\text{f}$ steps, as shown in Fig. 16-9b?

TABLE F

	Parallel Capacitors	Total Capacity	E_R	E_{tank}	I_{LINE} (ma)
1.	Start with $0.05\text{ }\mu\text{f}$	$0.05\text{ }\mu\text{f}$	12.7	122	12.7
2.	Remove $0.05\text{ }\mu\text{f}$, use $0.1\text{ }\mu\text{f}$	$0.1\text{ }\mu\text{f}$	10.7	123	10.7
3.	Add $0.05\text{ }\mu\text{f}$	$0.15\text{ }\mu\text{f}$	8.6	123	8.6
4.	Remove $0.05\text{ }\mu\text{f}$, add $0.1\text{ }\mu\text{f}$	$0.20\text{ }\mu\text{f}$	6.6	123	6.6
5.	Remove all capacitors, use $0.25\text{ }\mu\text{f}$	$0.25\text{ }\mu\text{f}$	5.0	123	5.0
6.	Add $0.05\text{ }\mu\text{f}$	$0.30\text{ }\mu\text{f}$	3.3	123	3.3
7.	Remove $0.05\text{ }\mu\text{f}$, add $0.1\text{ }\mu\text{f}$	$0.35\text{ }\mu\text{f}$	2.3	123	2.3
8.	Add $0.05\text{ }\mu\text{f}$	$0.40\text{ }\mu\text{f}$	3.1	123	3.1
9.	Remove $0.05\text{ }\mu\text{f}$, add $0.1\text{ }\mu\text{f}$	$0.45\text{ }\mu\text{f}$	5.0	123	5.0
10.	Add $0.05\text{ }\mu\text{f}$	$0.50\text{ }\mu\text{f}$	7.0	123	7.0
11.	Add $0.05\text{ }\mu\text{f}$	$0.55\text{ }\mu\text{f}$	9.2	123	9.2
12.	Add $0.05\text{ }\mu\text{f}$	$0.60\text{ }\mu\text{f}$	11.4	123	11.4
13.	Add $0.05\text{ }\mu\text{f}$	$0.65\text{ }\mu\text{f}$	13.8	123	13.8
14.	Add $0.01\text{ }\mu\text{f}$	$.36\text{ }\mu\text{f}$	2.2	123	2.2
15.	Remove $0.01\text{ }\mu\text{f}$, add $0.02\text{ }\mu\text{f}$	$.37\text{ }\mu\text{f}$	2.3	123	2.3
16.	Add $0.01\text{ }\mu\text{f}$	$.38\text{ }\mu\text{f}$	2.4	123	2.4
17.	Remove $0.01\text{ }\mu\text{f}$, add $0.02\text{ }\mu\text{f}$	$.39\text{ }\mu\text{f}$	2.9	123	2.9
18.	Add $0.01\text{ }\mu\text{f}$				

ELINE ~~100~~ volts

126

ERC ~~100~~ volts

1.5

 I_c branch 15 ma

Or is it exactly at the $0.35\text{-}\mu\text{f}$ step, as shown in Fig. 16-9c? We do not have enough measurements to tell. All that we know is that resonance occurs somewhere between the $0.30\text{-}\mu\text{f}$ and $0.40\text{-}\mu\text{f}$ steps. If you recorded similar measurements in Steps 8 and 9, you have this problem.

To locate the resonant point more closely, smaller changes in capacity must be made between the $0.30\text{-}\mu\text{f}$ and $0.40\text{-}\mu\text{f}$ steps, as were made in the series resonance experiments. You could start at the $0.30\text{-}\mu\text{f}$ step and add capacity in $0.01\text{-}\mu\text{f}$ steps until you reached $0.40\text{-}\mu\text{f}$. However, this won't be necessary. If you add $0.01\text{-}\mu\text{f}$ to the total capacity in the circuit at the step with the lowest current reading ($0.35\text{-}\mu\text{f}$ in our case), you can tell between which steps you must take further measurements. Let's see why this is so. Our lowest current reading was at the $0.35\text{-}\mu\text{f}$ step. If we add $0.01\text{-}\mu\text{f}$ to $0.35\text{-}\mu\text{f}$, we get $0.36\text{-}\mu\text{f}$. If the current decreases with $0.36\text{-}\mu\text{f}$ in the circuit, we know that resonance does not occur between the $0.30\text{-}\mu\text{f}$ and $0.35\text{-}\mu\text{f}$ steps and that no further measurements are necessary below the $0.35\text{-}\mu\text{f}$ point. For, in this case, resonance must be between $0.35\text{-}\mu\text{f}$ and $0.40\text{-}\mu\text{f}$. However, if the current rises with $0.36\text{-}\mu\text{f}$ in the circuit, then we know that there is no need to make further measurements above the $0.36\text{-}\mu\text{f}$ point and we must make measurements in $0.01\text{-}\mu\text{f}$ steps between $0.30\text{-}\mu\text{f}$ and $0.35\text{-}\mu\text{f}$.

TABLE G

Capacity	Current
$0.30\text{-}\mu\text{f}$	3.8 ma
$0.35\text{-}\mu\text{f}$	3.4 ma
$0.40\text{-}\mu\text{f}$	4.9 ma

In this case, resonance must be between $0.30\text{-}\mu\text{f}$ and $0.36\text{-}\mu\text{f}$.

Step 11. Add $0.01\text{-}\mu\text{f}$ to the capacity in the circuit at the step that gives the lowest line-current reading and take the usual readings. If the line current decreases, record your readings on line 14 of Table F, and continue taking measurements in $0.01\text{-}\mu\text{f}$ steps until you reach the next $0.05\text{-}\mu\text{f}$ step. Record these

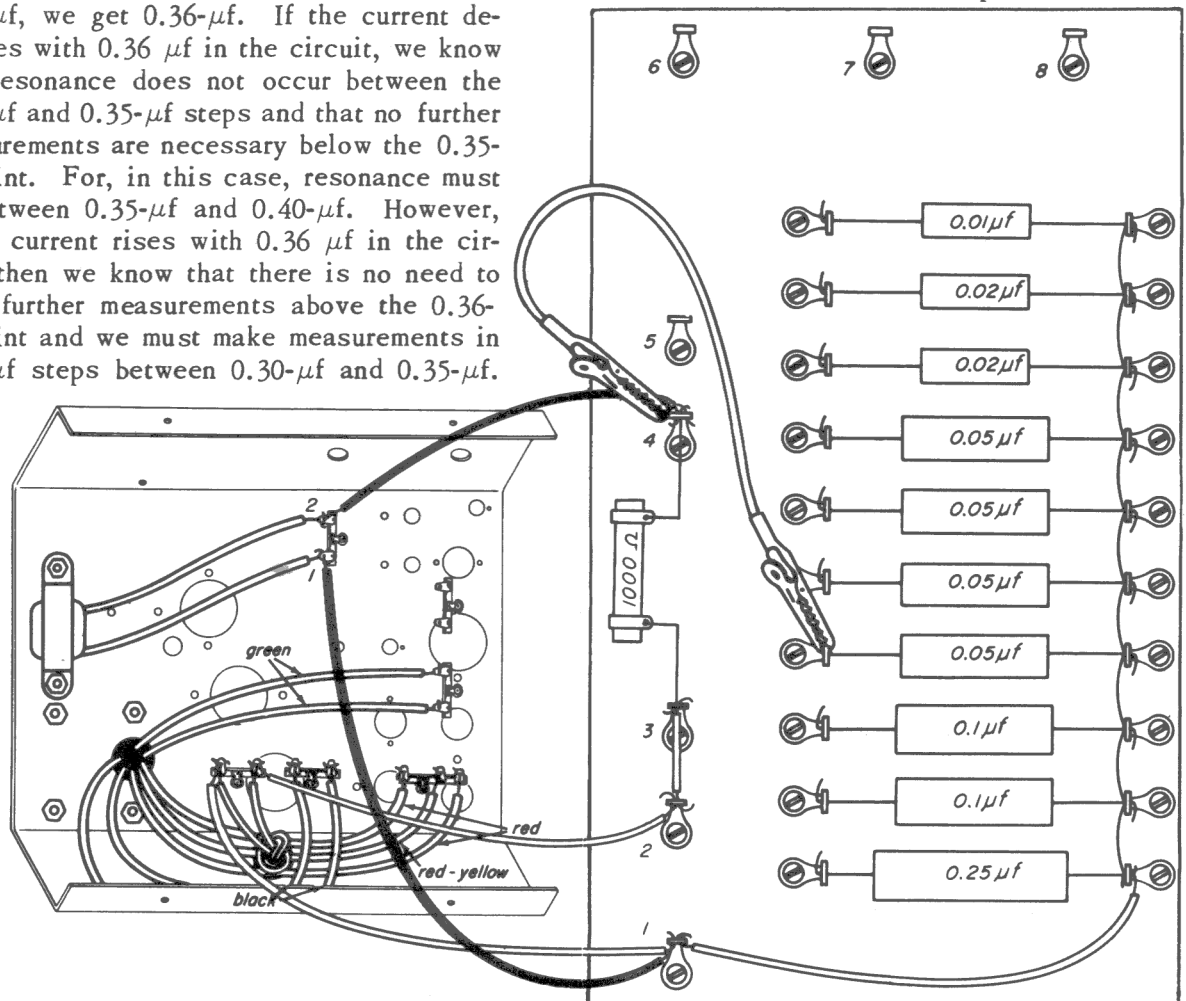


Fig. 16-8

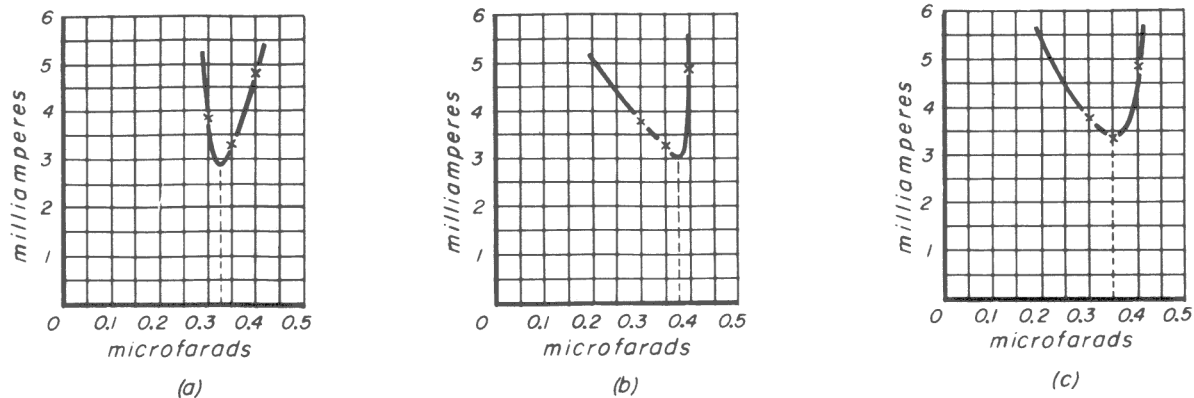


Fig. 16-9

measurements on lines 15 through 18 of Table F. However, if the line current rises with the addition of the first $0.01\text{-}\mu\text{f}$ increase, remove this $0.01\text{-}\mu\text{f}$ and one of the $0.05\text{-}\mu\text{f}$ capacitors. Then, starting at the next lower $0.05\text{-}\mu\text{f}$ step, add capacity in $0.01\text{-}\mu\text{f}$ steps, take your readings and record them on lines 14 through 18 of Table F. Be sure to record the capacity in the circuit for each of these steps in the second column of the table.

Step 12. After you have determined, as closely as possible, the amount of capacity that produces resonance, remove or add capacity to the capacitive branch until you again have this exact amount of capacity.

Step 13. Insert a 100-ohm resistor in series with the capacitive branch of the circuit, as shown in Fig. 16-10.

Step 14. Measure the voltage across the 100-ohm resistor (E_{RC}) and enter this voltage in the place provided at the bottom of Table F.

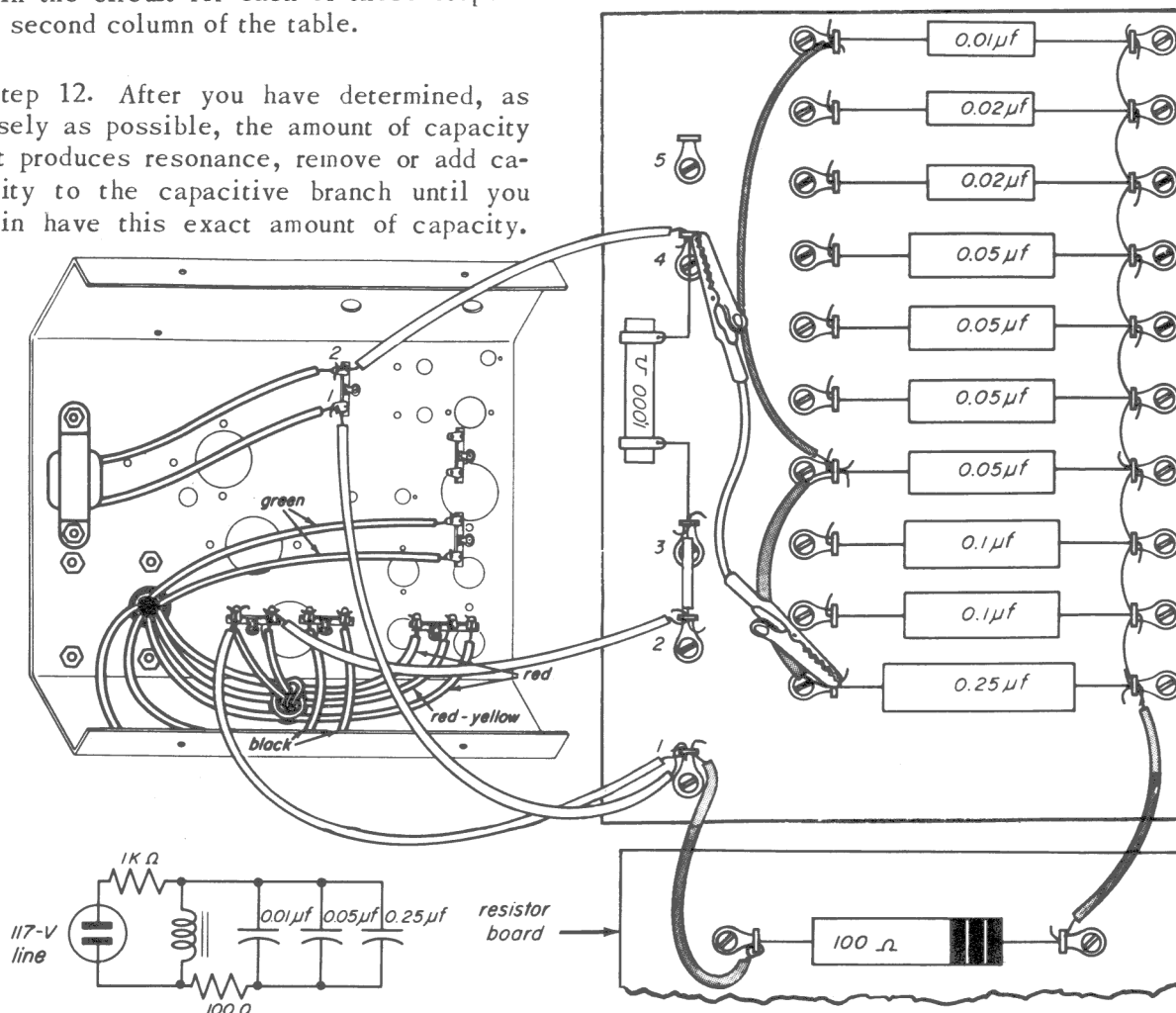


Fig. 16-10

Step 15. Calculate the current in the capacitive branch of the circuit:

$$I_C = \frac{E_{RC}}{100} = 15 \text{ ma}$$

Step 17. Calculate the impedance of the tank circuit at resonance:

$$Z(\text{resonance}) = \frac{\text{Voltage across tank}}{\text{line current}} = \frac{123}{.002 \times 2} = 55,909 \Omega$$

Enter this current in the place provided at the bottom of Table F.

Step 16. Plot the values of current against capacity on the graph paper provided in Fig. 16-11.

Discussion. This experiment shows the effects of resonance in parallel tuned circuits. The voltage readings that we obtained in our labs for this circuit are shown in Table H, and the curve plotted from these results is shown in Fig. 16-12. Your readings and curve will probably not be the same as

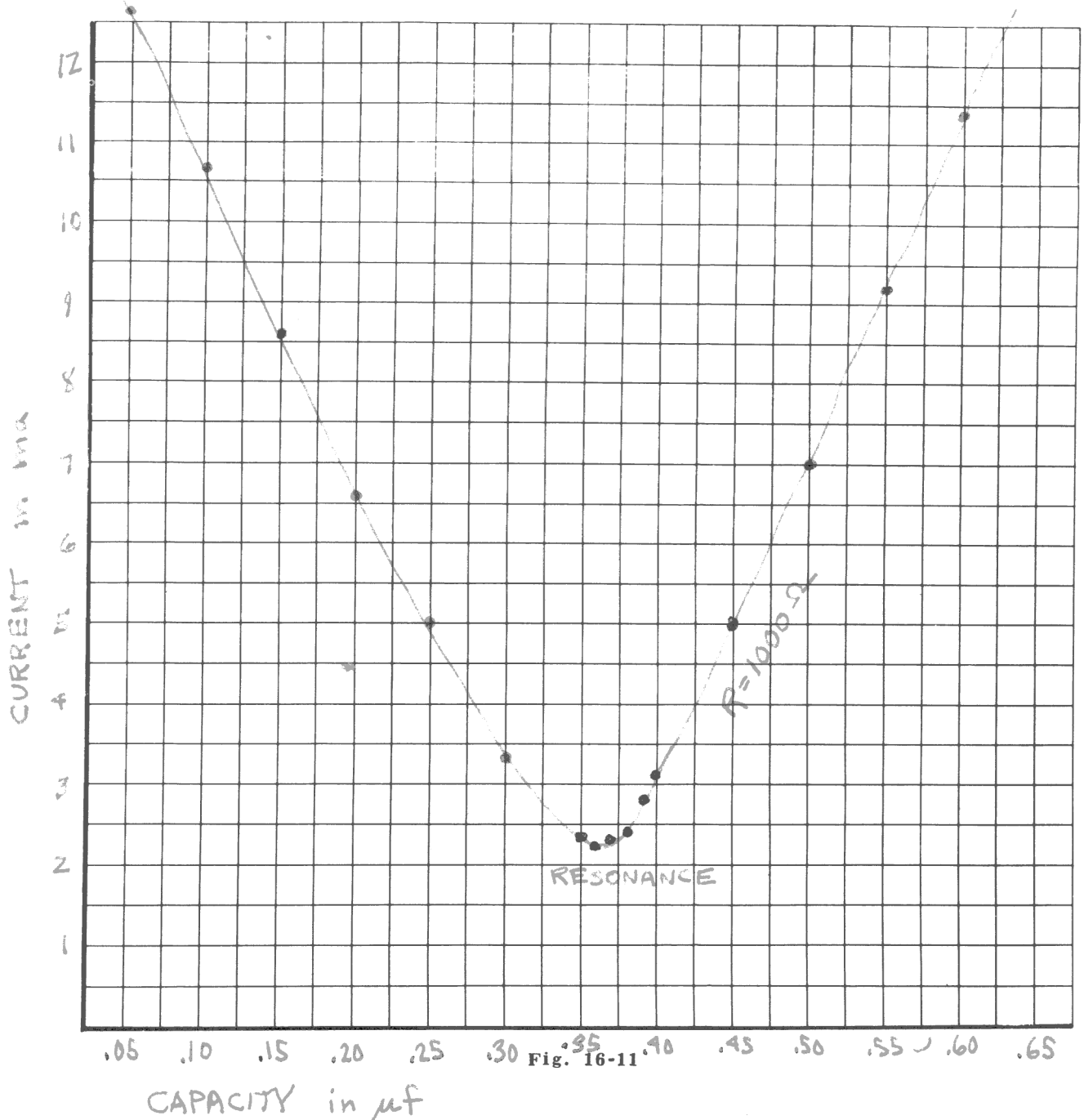


TABLE H
PARALLEL TUNED CIRCUIT

	Parallel Capacitors	Total Capacity	E_R	E_{tank}	I_{LINE} (ma)
1.	Start with 0.05 μf	0.05 μf	12	105	12
2.	Remove 0.05 μf , use 0.1 μf	0.1 μf	10.5	105	10.5
3.	Add 0.05 μf	0.15 μf	8.5	106	8.5
4.	Remove 0.05 μf , add 0.1 μf	0.20 μf	6.9	106	6.9
5.	Remove all capacitors, use 0.25 μf	0.25 μf	4.6	107	4.6
6.	Add 0.05 μf	0.30 μf	3.8	107	3.8
7.	Remove 0.05 μf , add 0.1 μf	0.35 μf	3.4	107	3.4
8.	Add 0.05 μf	0.40 μf	4.9	107	4.9
9.	Remove 0.05 μf , add 0.1 μf	0.45 μf	6.6	106	6.6
10.	Add 0.05 μf	0.50 μf	8.7	105	8.7
11.	Add 0.05 μf	0.55 μf	10.8	105	10.8
12.	Add 0.05 μf	0.60 μf	13.0	105	13.0
13.	Add 0.05 μf	0.65 μf	15.0	105	15.0

APPROACHING RESONANCE

14.	Add 0.01 μf	0.31 μf	3.5	107	3.5
15.	Remove 0.01 μf , add 0.02 μf	0.32 μf	3.3	107	3.3
16.	Add 0.01 μf	0.33 μf	3.2	107	3.2
17.	Remove 0.01 μf , add 0.02 μf	0.34 μf	3.3	107	3.3
18.	Add 0.01 μf	0.35 μf	3.4	107	3.4

E_{LINE} 110 volts

E_{RC} 1.25 volts

$I_{\text{c branch}}$ 12.5 ma

these; they are given only so that you will have some idea of what your results should be like.

Your measurements and plotted curves illustrate the following important points regarding a parallel a-c circuit containing inductance and capacitance when it is at resonance:

1. The line current is at its minimum.
2. The impedance of the tank circuit is at its maximum value, and is much higher than the impedance of either the inductive branch or the capacitive branch.
3. The line current is less than the current in either of the branches.

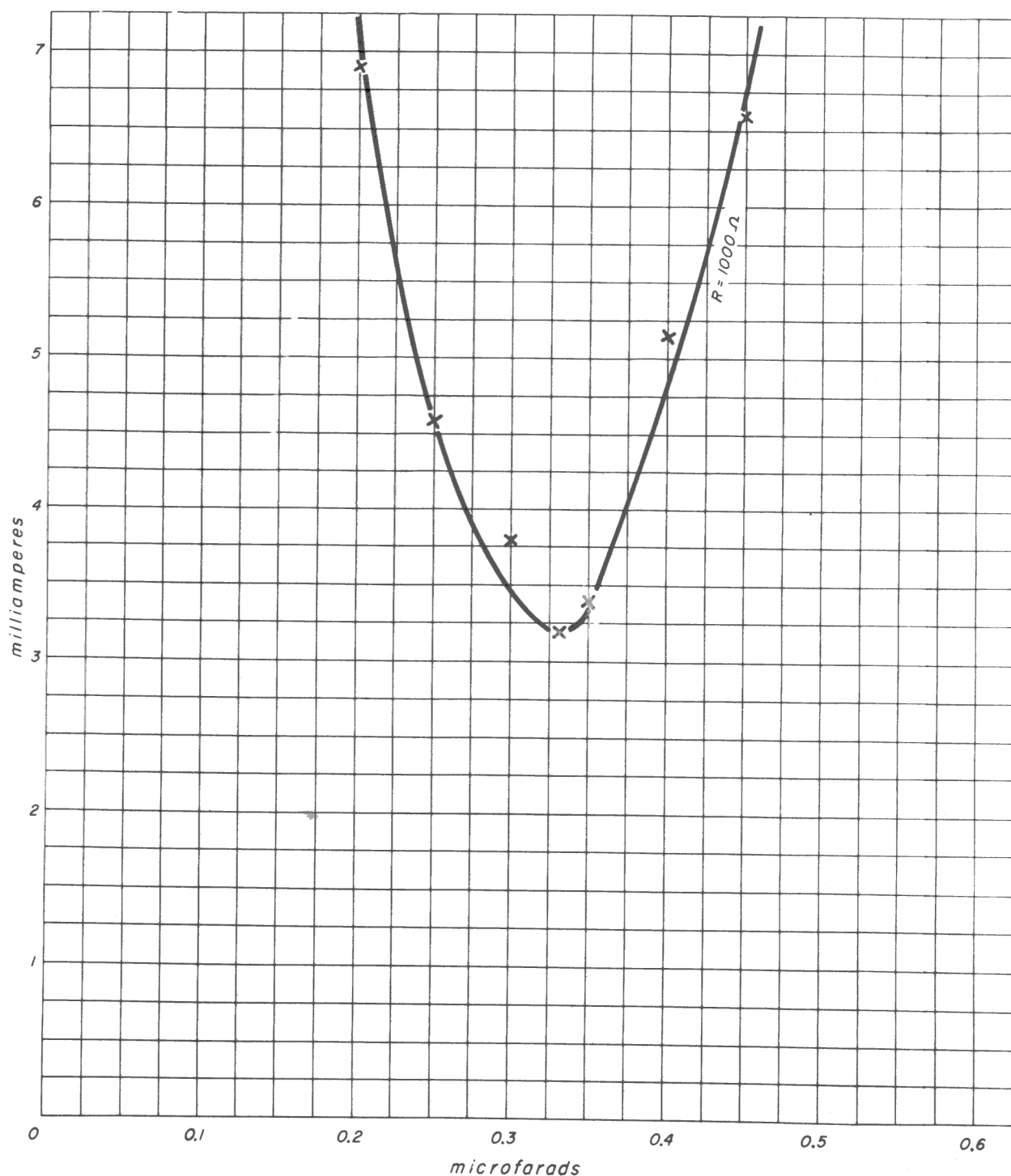


Fig. 16-12

4. The voltage across the parallel circuit is at its maximum.

Resonance occurs in parallel a-c circuits containing inductance and capacitance because the current taken by the inductive branch is opposite in phase to the current taken by the capacitive branch of the circuit. Because of this phase relationship, current for the capacitor is supplied by the energy stored in the inductor, and current for the inductor is supplied by the energy stored in the capacitor. As a result, the parallel circuit, at resonance, accepts very little current from the line. This is what makes its impedance very high, and accounts for the fact that the line current is less than the current in the branches.

In a parallel circuit containing perfect inductors and capacitors, the current taken by the inductive branch would be exactly equal to the current taken by the capacitive branch, and the currents would also be exactly 180 degrees out of phase. In this case, no current would be taken from the line, and the impedance of the parallel circuit would be infinite. However, because of the fairly high resistance in the filter choke, and the slight resistance in the capacitor, these currents can never be exactly equal, and they can never be exactly 180 degrees out of phase. The current taken by the two branches does not cancel out, and some current is taken from the line. It is very small, as your measurements will show, and the impedance of the parallel circuit is very high. This exchange of energy between the inductor and the capacitor in a parallel-tuned circuit is extremely important in almost every part of radio and electronics, as you will see when you progress further in your studies.

PLOTTING GRAPHS

Tables of figures such as the one shown below are not easy to understand at a glance. It is much easier to see the story told by the figures when they are plotted in the form of a graph. In a previous lesson, you learned how to read a graph. Now let us see how to take a table of figures or data from an experiment and prepare a graph from them.

TABLE 1	
Time	Distance
0 sec	0 feet
1 sec	4 feet
2 sec	6 feet
3 sec	14 feet
4 sec	26 feet
5 sec	50 feet

Table 1 shows the results of measurements taken to find out the distance covered by a certain automobile in a certain amount of time. The measurements were taken at the end of each second, and the distance from the starting point is given in the table for each second up to five seconds. How do we go about transforming this table of figures into a graph? You know that one of the quantities, time for instance, is measured off along one of the axes, and the other quantity, distance, is measured off along the other axis. But shall we use the horizontal axis for the time and the vertical axis for distance, or the other way around? By long established convention, the *independent variable* is measured off along the horizontal axis. The independent variable is the one over which you have complete control and can select in advance in any way that you wish. For example, if you were standing with stop watch in hand to measure the distance covered by a certain automobile, you could make your measurements at the end of every half-second, or at the end of every second, or every two seconds, or in any way that you wished. The choice is entirely up to you, making time the independent variable. Time is therefore measured off along the horizontal axis, as in Fig. 16-13. But, the distance traveled by the automobile depends on how long it has been moving. In this case, the distance depends upon the time, and the time does not depend on the distance. The distance is therefore called the *dependent variable*, and it is measured off along the vertical axis, as in Fig. 16-13.

The next thing that we must decide on is the scale to use for the graph. The scale

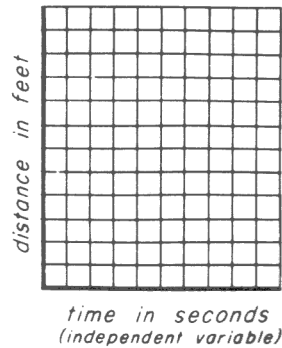


Fig. 16-13

depends upon the numbers that we have to plot, and the size and type of graph paper. The piece of graph paper that we are going to use is shown in Fig. 16-14. It has ten spaces across. Since our data covers five seconds, divide the number of seconds by the number of spaces, which gives or, in

$$\frac{5 \text{ seconds}}{10} = \frac{1}{2} \text{ second per space}$$

other words, 2 spaces per second, as shown in the figure. The distance covered is going to be measured off along the vertical axis. Here there are twenty spaces vertically for the graph. The data covers fifty feet, so that

$$\frac{50 \text{ feet}}{20} = 2.5 \text{ feet per space}$$

or, in other words, every two spaces represent five feet, as shown in the figure.

Now that the axis for the graph are labelled and marked off in the proper units, we can begin to plot the graph. At zero time, the

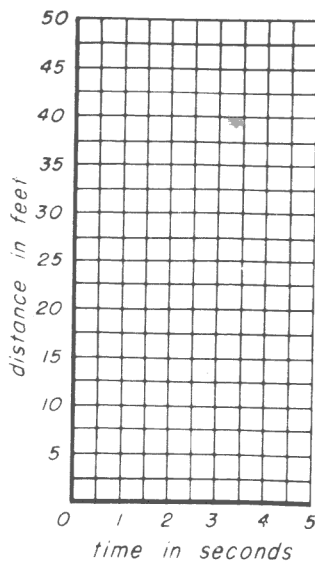


Fig. 16-14

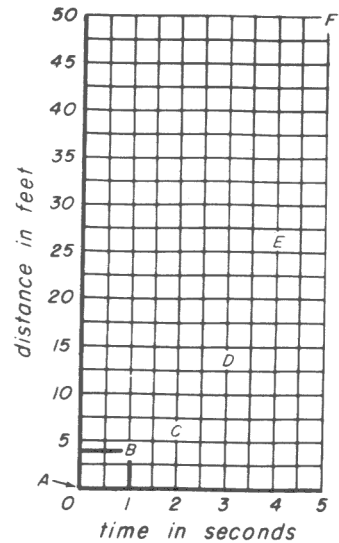


Fig. 16-15

distance is zero, and that gives point *a* on our graph, as shown in Fig. 16-15. After one second, the distance traveled is four feet. To plot this point, find four feet on the vertical axis. This point is not labelled on the axis, so you must estimate where four feet is along the distance from zero to five. Having located this point, draw a line horizontally across until it intersects (cuts across) the line that is coming up from one second. The intersection of these two lines is the point representing four feet at one second, and it is labelled *b* on the graph. In the same way, the rest of the points are plotted, as shown in the figure.

After all the points have been plotted, they must be connected in order to complete

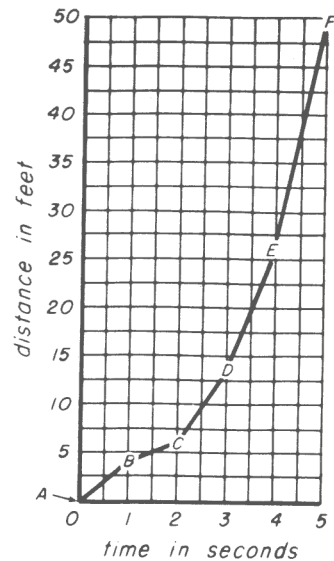


Fig. 16-16

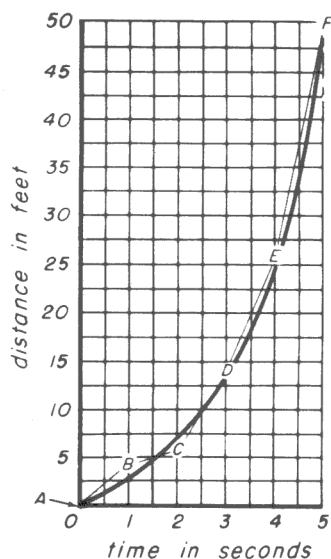


Fig. 16-17

the graph. One way of connecting the points is with straight lines, as shown in Fig. 16-16. However, our experience tells us that this cannot be right, because unless you pump your foot up and down on the gas pedal, the automobile does not move in jerks as the graph now seems to show. The correct way to connect the points of most graphs is with a smooth curve, as shown in Fig. 16-17. (Smooth curves are used to connect the points unless we have reason to believe, from the nature of the experiment, that in between the points the change does not come about in a smooth manner.) Notice also that the curve does not pass right through points *b* and *c*. If there are any points, such as *b* and *c*, that cannot be connected by a smooth curve, the curve should not be distorted in order to make it pass through those points. Instead, the curve should be made to take the average path between the points as shown in the figure. The reason that points *b* and *c* lie off the curve is probably because of some error in the instruments used or in making the readings. Thus, by drawing a smooth curve between these points, this error is minimized. However, these points are never erased, but left on the graph as shown in Fig. 16-18, even though the curve does not pass through them. This is done so that there is a record of the original points obtained by measurement, and

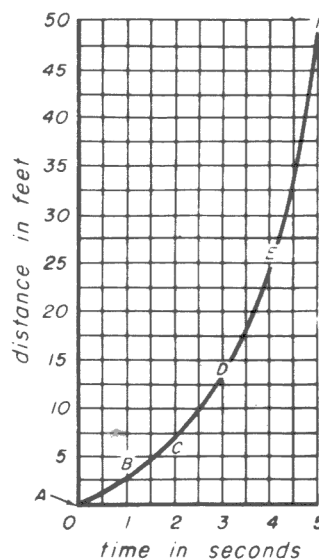


Fig. 16-18

when you look at this graph at some later time, or when someone else looks at your graph, it will be clear what has been done.

Having finished your graph, notice how much easier it is to read than the column of figures. The graph shows at a glance how the automobile starts off very slowly and then gradually picks up speed once it has started moving.

Now let us apply what you have learned about plotting of graphs to the plotting of resonance curves from the data obtained in this experiment. Since you select the capacity at which the measurements are taken, capacitance is plotted as the independent variable along the horizontal axes. Using the principles just described, label your axis and decide on the scale you will use for capacity and the scale you will use for current. Plot on the same sheet the data taken with the 1,000-ohm resistor and the 2,000-ohm resistor. When you have finished you can compare your graph with the one shown in Fig. 16-7. They may not look the same, since you may have slightly different current readings, and you may set up a different scale than the one given. But if you have done it correctly, the general shape of the graph will be the same, and the story it tells will be the same!